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Goddard Space Flight Center
Greenbelt, Maryland 20771
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The Earth Observing System Terra Series

These articles focus on the overarching science priorities of the EOS Terra mission
http://terra.nasa.gov

Changing Global Cloudiness

Clouds are visible collections of small particles of water or ice, or both, suspended in the atmosphere. They are one of the most obvious and influential features of Earth's climate system. They are also one of its most variable components. The natural diversity and variability of clouds has intrigued and challenged researchers for centuries.

How Do Clouds Form?

In order to form, clouds require the presence of water vapor and aerosols (tiny solid or liquid particles suspended in the atmosphere)—both are found abundantly in Earth's atmosphere (see Aerosols FS-1999-06-022-GSFC). Water vapor, or water in its gaseous state, is transferred from the surface to the atmosphere primarily via either evaporation or "evapotranspiration," (the process by which water is evaporated from the tiny openings on the leaves of plants during respiration).

As air currents rise, taking water vapor molecules along with them, they tend to cool. This vertical motion of air currents helps clouds form, by exposing its water vapor to both cooler temperatures and cloud condensation nuclei (CCN—aerosol particles up to one-millionth of a meter in size) also suspended in the atmosphere. There are many types of CCN, ranging from sea salt to windblown dust to industrial pollution. These nuclei are hygroscopic ("water-attracting") while others (oils, Teflon) are hydrophobic ("water-repelling") (Figure 1). Since hygroscopic nuclei have an affinity for water, they act as "seeds" to accelerate the condensation process to convert water from its gaseous to its liquid phase.

In the presence of CCN, clouds form in either of two ways: (1) when a region of atmosphere cools to the temperature at which water vapor condenses into water droplets or is deposited into ice crystals; or (2) when sufficient amounts of water vapor are added to a given region of atmosphere, yielding the formation of water droplets (condensation) or ice crystals (deposition.)

Clouds and Climate Change

Until recently, scientists did not know whether clouds had a net cooling or heating effect on global climate. Clouds reflect solar radiation, which tends to cool the climate, but they also help contain the energy that the Earth would otherwise emit to space, which tends to warm the climate. Measurements made in the 1980s by NASA's Earth Radiation Budget Experiment (ERBE) satellite demonstrated that clouds have a small net cooling effect on the current global climate. As human-induced processes (e.g., deforestation, release of greenhouse gases) increasingly affect our climate, it becomes more critical to gain a precise understanding of how climate variations can alter the physical and chemical processes that govern cloud formation and dissipation.

We must also determine to what extent resulting changes in cloud patterns will affect climate as a result of their effects on Earth's "energy balance" (see Earth's Energy Balance FS-1999-06-025-GSFC). If we measure the total amount of solar energy Earth receives from the sun, then we deduct from that number the total amount of sunlight reflected and the heat emitted from

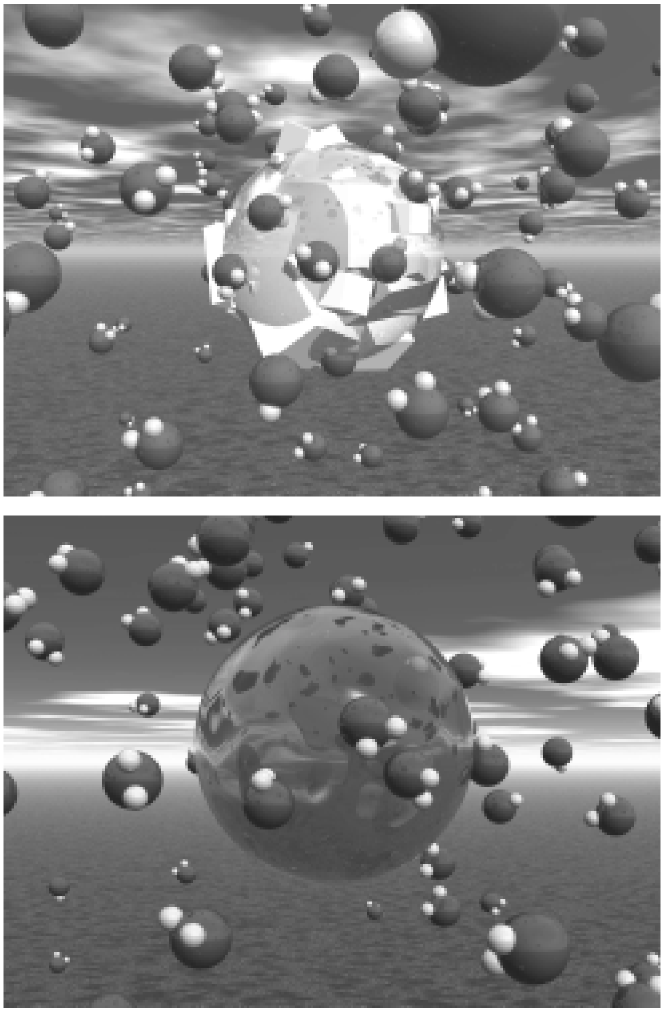

Figure 1. Hygroscopic nuclei (top) consist of particles such as sea salt and common table salt which have an affinity (attraction) for water. Water vapor condenses on these particles when the relative humidity is considerably less than 100 percent. On humid days, you may find it difficult to pour salt from the shaker because water vapor has condensed on the salt crystals, sticking them together. Hydrophobic nuclei (bottom) consist of particles such as oils and Teflon. These nuclei resist condensation even when the relative humidity is greater than 100 percent.

Earth, then we arrive at a number referred to as Earth's "energy budget." Because global measurements to date suggest that the amount of incoming radiant energy is roughly equal to the amount that is outgoing, we say there is an "energy balance." But a small percentage change in cloud cover could have a significant effect on Earth's energy balance.

A key to predicting climate change is to observe and understand the global distribution of clouds, their physical properties (such as thickness and droplet size), and their relationship to regional and global climate. Because clouds change rapidly over short time and space intervals, they are difficult to simulate in computer models and, therefore, their contribution to climate change is difficult to quantify. Improving our understanding of clouds and refining our predictive models of their behavior will also aid weather forecasting.

Current global change models are hampered by insufficient understanding of certain fundamental physical processes. NASA's Terra spacecraft will obtain a variety of precise measurements of cloud properties to feed improved climate models. Terra will yield improvements in our knowledge of cloud water droplet and ice crystal content, as well as how the feedback loops between Earth's air, land, and ocean work from day to day.

Surface-Based and Satellite Cloud Observations

The existing long-term collection of cloud measurements made by surface observers provides an important baseline record of cloud phenomena. Although these historical observations provide a useful context in which to study clouds, they do not provide the data that scientists need to conduct a more thorough and detailed study. Specifically, scientists require observations to be taken more frequently (at least daily), over much wider areas (up to global scale), and at many more wavelengths of the electromagnetic spectrum than can be detected by the human eye, ranging into the infrared (or heat) region. In short, satellites can provide much more quantitative data than can be gathered by surface observations.

The International Satellite Cloud Climatology Project, begun in the early 1980s, is an effort to take advantage of the visible light and infrared information currently available from existing meteorological satellites by constructing a detailed database of average global cloud cover and cloud types (Figure 2). Although these observations are useful, their spatial resolution is limited to about 2.5 miles (four kilometers), and data are available only at two wavelengths—one in visible light and one in the infrared region of the spectrum. While these data allow estimations of cloud top pressure, cloud coverage, and cloud optical depth (a measure of the amount of sunlight that passes through), they still do not provide the detail scientists need to accurately model the roles clouds play in climate change.

Studies show that observations with a spatial resolution of about 800 feet (250 meters) are needed to accurately resolve cloud distributions. With observations at multiple wavelengths of the electromagnetic spectrum, the size of cloud particles and more accurate estimates of cloud radiative effects can be obtained. In addition, observations taken at several viewing angles are necessary to better define the effects of clouds on climate.

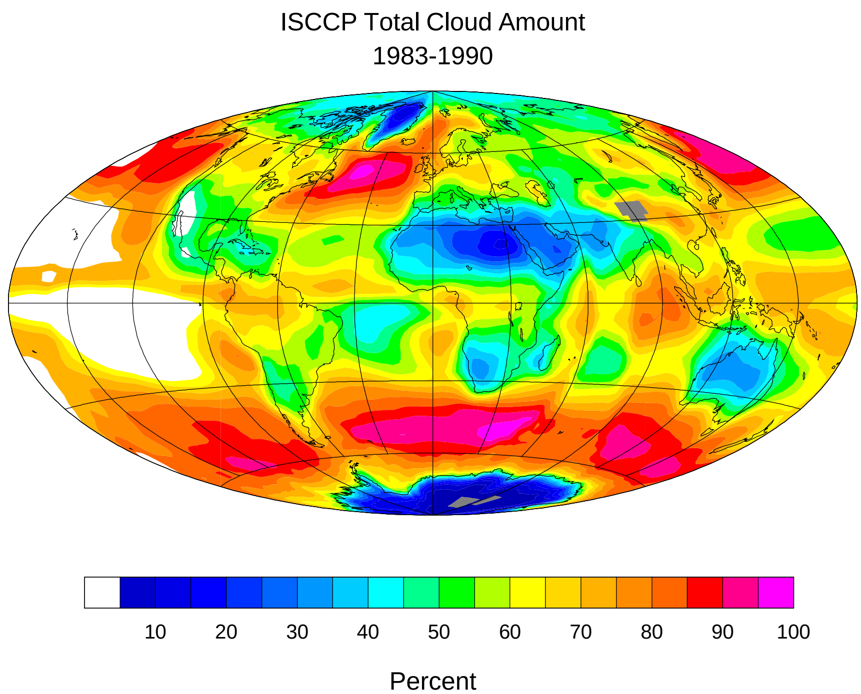

Figure 2. Total fractional cloud cover annually averaged from 1983-1990.

Terra and Cloud Observations

NASA's Terra satellite will observe how clouds interact with Earth's energy budget on a global scale, as well as provide detailed measurements of clouds' structures and droplet sizes. Four of the five sensors aboard Terra will work together in different combinations to make important new measurements of clouds.

The Moderate-Resolution Imaging Spectroradiometer (MODIS) and Multi-Angle Imaging SpectroRadiometer (MISR) will enable us to view clouds' features at higher resolution—an improvement that will take scientists from the half-mile range available on satellites today, to as sharp as about 800 feet (250 meters.) Both of these instruments take observations at several wavelengths in the electromagnetic spectrum, enabling cloud droplet size measurements, which are critical to understanding the optical and physical properties of clouds.

In addition to an improved "spectral resolution," MODIS takes measurements at several wavelengths in the heat emission spectra of Earth. These measurements will allow scientists to more precisely determine the contributions of clouds to the greenhouse warming of Earth.

With cameras pointed in nine directions, the multi-angle views of the MISR instrument will observe the angles at which sunlight is reflected from clouds. These observations will be critical to new research on the radiative properties of clouds.

For climate-related studies, the Clouds and the Earth's Radiant Energy System (CERES) instrument will help fill gaps in the parts of the solar spectrum that MISR and MODIS cannot see. CERES together with MODIS and MISR will greatly improve understanding of the links between the variability of net incoming sunlight (shortwave radiation) and net outgoing heat (longwave radiation) and its connection to cloud structure and coverage.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) provides very high spatial resolution measurements (50-300 feet [15-90 meters]) at a number of visible and infrared wavelengths. ASTER will complement the other instruments by providing sporadic, high-resolution views at specific targets of interest.

Cloud-related studies made possible by Terra should produce more accurate and comprehensive observations of Earth's cloud cover. These observations are important for developing improved models of Earth's climate, both for seasonal and longer-term climate predictions. Terra's data will give us new insights into how clouds modulate atmospheric and surface temperature, atmospheric humidity, atmospheric and oceanic circulation and precipitation patterns, all of which affect our daily lives in fundamental ways, from recreation to fishing to farming.

The Terra Spacecraft

Terra is the flagship of the Earth Observing System (EOS), a series of spacecraft to observe the Earth from the unique vantage point of space. Focused on key measurements identified by a consensus of U.S. and international scientists, EOS will enable research on the complex interactions of Earth's land, ocean, air, ice and life systems.

Terra will circle the Earth in an orbit that descends perpendicularly across the equator each day at 10:30 a.m. local time, when cloud cover is at a minimum and the space-based view of the surface is least obstructed. Each individual swath of measurements can be compiled into global images as frequently as every two days. Over a month or more, in combination with measurements from other polar orbiting satellites, Terra measurements will provide accurate monthly-mean climate assessments that can be compared with computer model simulations and predictions.

The Earth Observing System has three major components: the EOS spacecraft, an advanced ground-based computer network for processing, storing, and distributing the resulting data (the EOS Data and Information System); and teams of scientists and applications specialists who will study the data and help users in industry, universities and the public apply it to issues ranging from agriculture to urban planning.

Additional information on NASA's Terra mission can be found on the World Wide Web at http://terra.nasa.gov.